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A MODEL FOR INCORPORATING CHANGES IN DISTRIBUTION OF FISHING EFFORT IN ASSESSMENT OF THE EFFECTS OF CHANGES IN TRAWL MESH SIZE

By

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ABSTRACT

ULLTANG, Ø. 1983. A model for incorporating changes in distribution of fishing effort in assessment of the effects of changes in trawl mesh size. *FiskDir. Skr. Ser. HavUnders.*, *17:* 000–000.

Factors invalidating traditional mesh assessments are discussed with special emphasis on changes in distribution of fishing effort between areas inhabited by small and large fish. A model for studying the effects of such changes is constructed.

Both studies of equilibrium situations and simulation studies, taking into account variations in year class strength, show that traditional mesh assessments may significantly underestimate the long term effects of mesh size changes. The short term effects will depend on the age composition in the stock when the mesh change is introduced and on the incoming recruitment.

Finally the more general applicability of the model is discussed.

INTRODUCTION

Assessments of the effects of changes of minimum legal trawl mesh sizes are usually carried out by calculating "short term losses" and "long term gains", assuming no change in total fishing effort or its distribution by area and season (GULLAND 1961). Short and long term effects are calculated from the estimated selection parameters of the old and new mesh sizes and the established exploitation pattern (exploitation pattern = distribution of fishing mortalities with age) with the old mesh size. In a working paper to a meeting of the FAO Advisory Committee for Marine Resources Research (ACMRR), the author (ULLTANG 1975) discussed the effects of changes in the distribution of fishing effort generated by an increase in the minimum legal mesh size. Such changes will generally increase the effects of a mesh size change.

In the present paper, following a summary of the results given in ULLTANG

(1975), such effects will be further evaluated, assuming that a given total fishing effort (constant over the year) is free to move between the areas of distribution of the various age groups.

FACTORS INVALIDATING TRADITIONAL MESH ASSESSMENTS

Assume that a given fishing fleet generates a fishing mortality F_{i,m_1} on age group i with a mesh size m_1. If the mesh size is increased to m_2, it is usually assumed in mesh assessments that

$$F_{i,m_2} = \frac{p_{i,2}}{p_{i,1}} F_{i,m_1}$$

where $p_{i,2}$ and $p_{i,1}$ are the proportions of age group i retained in the new and old net respectively, the p's being estimated from trawl selection experiments. Thus, the increase in mesh size will only effect the fishing mortality on age groups younger than those fully retained by the new net, and the effect on those age groups are completely determined by the estimated selection parameters. There are two factors which may invalidate this assumption:

(i) An increased mesh size may have some effect on the catchability coefficient q ($F = qE$, where F is fishing mortality on the fully retained age groups and E is fishing effort).

(ii) If the various size groups are partially separated by areas, a larger part of the fishing effort may be directed towards older fish when the catch per unit of effort (cpue) of younger fish decreases as a result of the selectivity.

In this study the effects of factor (ii) will be investigated. This factor will have both an immediate and longterm effect on the exploitation pattern and thus invalidate any mesh assessments carried out by traditional methods. Factor (i) in isolation would only influence the exploitation rate or level of fishing mortality generated by the fishing fleet. If the exploitation rate is regulated by a TAC, the presence of this factor would mean that the fishing effort required to take the TAC would be different from what was estimated. This would have no effect on a stock prognoses. However, it should be noticed that factor (i) will affect calculations of "short terms losses", i.e. the decrease in cpue following an increase in mesh size. If q increases with mesh size, "short term losses" will be overestimated by the methods traditionally used. It should, however, be noted that the term "short term losses" is ambiguous under a regime of TAC regulations, as discussed by Ulltang (1979).

A MODEL FOR INCORPORATING CHANGES IN DISTRIBUTION OF FISHING EFFORT

EQUILIBRIUM SITUATIONS

ULLTANG (1975) illustrated the effect of a changing fishing pattern generated by an increased trawl mesh size by the following very simplified example:

Assume a fishing fleet is exploiting a stock where,

Weights at age are equal to those for Arcto-Norwegian cod (ANON. 1973)
Natural mortality (M) = 0.2
Age of first spawning = 8 years
All fish younger than 8 years old are in an area A, and all fish 8 years old and older are in an area B (separate from area A).

In Fig. 1 are given the yield per recruit and spawning stock per recruit for three different mesh selection alternatives assuming the same fishing mortality in the two areas A and B. The three mesh selection alternatives were as follows[1] (F_i = fishing mortality on age group i):

Selection a):	$F_{i<3} = 0$	$F_3 = 0.3F$	$F_4 = 0.6F$	$F_5 = 0.9F$	$F_{i>5} = F$
Selection b):	$F_{i<4} = 0$	$F_4 = 0.3F$	$F_5 = 0.6F$	$F_6 = 0.9F$	$F_{i>6} = F$
Selection c):	$F_{i<5} = 0$	$F_5 = 0.3F$	$F_6 = 0.6F$	$F_7 = 0.9F$	$F_{i>7} = F$

The curves are also given for the situation where there is no fishing in area A.

If a total fishing effort E_T is applied on this stock, splitted on E_A in area A and E_B in area B, and the relationship

$$F = q\,E \quad (F = \text{fishing mortality},\ q = \text{catchability coefficient})$$

is assumed to be valid in both area A and area B separately, a high fishing mortality in area A will imply a low fishing mortality in area B, and vice versa. We have:

$$E_T = E_A + E_B = \frac{F_A}{q_A} + \frac{F_B}{q_B}, \text{ i.e.}$$

$$F_B = q_B\,E_T - \frac{q_B}{q_A}\,F_A$$

[1] The selection altrnatives were chosen rather arbitrarily and not calculated from any selection factors and growth parameters, i.e. constructed just to ensure that the proportion retained in the net of age groups within a certain age range was decreasing with an increasing mesh size.

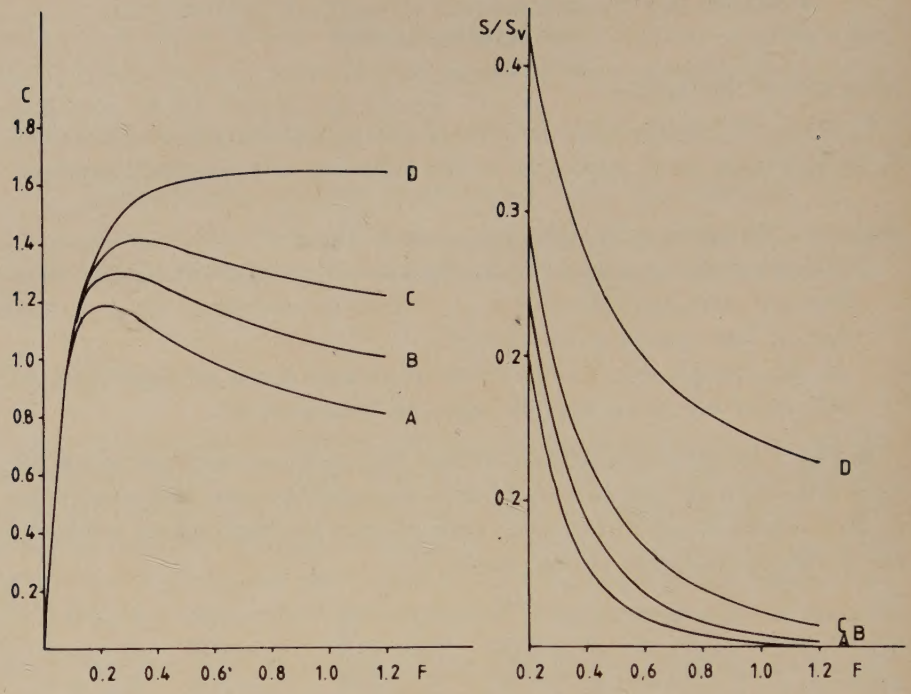

Fig. 1. Yield per recruit (C) and spawning stock per recruit (S/S_v where S_v = spawning stock per recruit in unexploited stock) against fishing mortality (F). A: Mesh selection a). B: Mesh selection b). C: Mesh selection c). D: No fishing in area A. For further explanation see text.

The catch per unit of effort in the two areas is given by

$$(C/E)_A = \frac{q_A}{F_A} C_A$$

$$(C/E)_B = \frac{q_B}{F_B} C_B$$

In Fig. 2 are shown for the three different mesh selections the yield per recruit in area A, area B and the total area together with the catch per unit of effort (per recruit) when

$$q_A = q_B = 1.2 \text{ and } E_T = 0.5, \text{ i.e.}$$
$$F_B = 0.6 - F_A$$

In the calculations it was assumed that a certain combination of F_A and F_B had been applied for a period sufficiently long for establishing an equilibrium situation.

For mesh selection a) the catch per unit of effort is higher in area A than in area B when $F_A < 0.51$ (i.e. $F_B > 0.09$). If it is assumed that the effort will go to

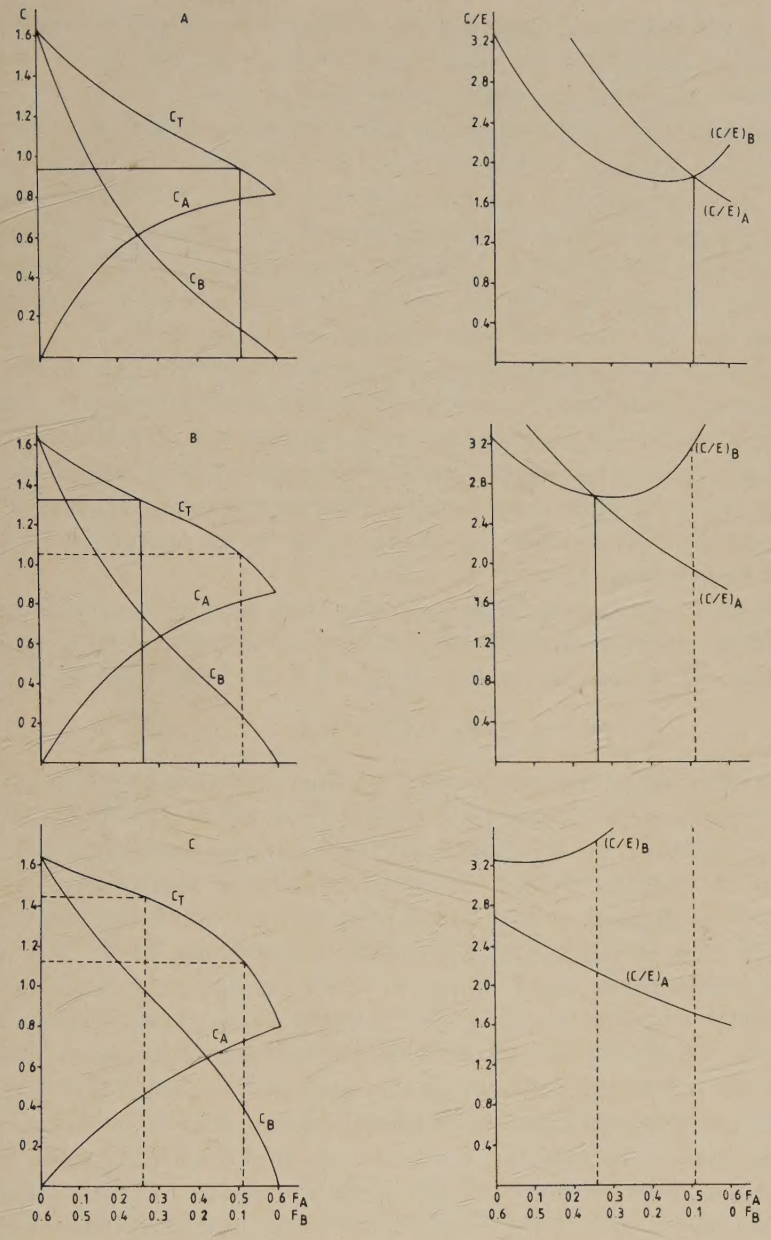

Fig. 2. Yield per recruit and catch per unit of effort (per recruit) for different combinations of fishing mortalities in area A (F_A) and area B (F_B) for mesh selection a (A), b (B) and c (C) when $F_A + F_B = 0{,}6$. C_A, C_B and C_T: The yield in area A, area B and the total area reapectively. $(C/E)_A$ and $(C/E)_B$: The catch per unit of effort in area A and area B. For further explanation see text.

the area with the highest catch per unit of effort, this will tend to establish an equilibrium situation at the point where $(C/E)_A = (C/E)_B$, i.e. $F_A = 0.51$, $F_B = 0.09$. The yield per recruit would then be 0.94.

If the mesh size is changed to alternative b), the catch per unit of effort in area A will decrease relative to area B. The equilibrium point where $(C/E)_A = (C/E)_B$ would in this case be at $F_A = 0.26$, $F_B = 0.34$. If F_A and F_B did not change, an increase in mesh size from a) to b) would give an increase in yield per recruit from 0.94 to 1.05 only. If in addition the fishing pattern is changed to the situation where $F_A = 0.26$, $F_B = 0.34$ as a result of the change in mesh size, the yield per recruit would increase to 1.33.

If the mesh size is changed to alternative c), the catch per unit of effort will be higher in area B than in area A for all possible combinations of F_A and F_B, i.e. all the effort would tend to go to area B, resulting in $F_B = 0.6$, $F_A = 0$, and a yield per recruit value of 1.63. Again, if the change in fishing pattern resulting from an increase in mesh size from b) to c) had not been taken into account, the estimated effect of the mesh size change would be an increase in yield per recruit from 1.33 to 1.44.

In Table 1 yield per recruit and spawning stock per recruit values are given for equilibrium situations estimated as above for four different sets of values of the parameters q_A, q_B and E_T. If $q_A = q_B = 1.2$ (as in Fig. 2) but $E_T = 1$, i.e.

$$F_B = 1.2 - F_A$$

then all effort will be in area A for mesh selection a) creating a fishing mortality of 1.2. If mesh size is changed to alternative b), all effort still will be in area A, but there will be some increase in yield and spawning stock per recruit as a result of the mesh size change. If mesh size is increased to alternative c), some effort will be diverted to area B, but most of it will still be in area A. The situation must be characterized as highly unsatisfactory for all three mesh selection alternatives, and it illustrates a more general point. In a "growth overfishing"-situation (CUSHING 1972) created by too heavy fishing, effort inevitably will tend to concentrate on the younger year classes because of lack of old fish. In the case illustrated in the upper part of Table 1 ($E_T = 1$), the total fishing effort is so high that a moderate increase in mesh size from a) to b) will not increase the spawning stock size (the stock in area B) to the extent necessary to make the catch per unit of effort of mature fish higher than the catch per unit of effort in the young fish area, and all effort therefore still will concentrate on the recruiting year classes. If the total effort is cut down to half ($E = 0.5$), a change in mesh size from a) to b) will have a significant effect on the fishing pattern as illustrated in Fig. 2 and Table 1.

In the lower part of Table 1 the catchability coefficient in area A is assumed to be 0.6, i.e. half that assumed in the upper part of the table giving

$$F_B = 1.2 - 2\ F_A$$

Table 1. Equilibrium situations for different combinations of catchability coefficients, total effort and mesh selection pattern. C_{max}= maximum sustainable catch when all effort is in area B. S = spawning biomass per recruit. S_v = spawning biomass per recruit in unexploited stock. For further explanation see text.

q_A	q_B	E_T	Selection	E_A	E_B	F_A	F_B	C_A[1]	C_B[1]	C_T[1]	$(C/E)_A$[1]	$(C/E)_A$[1]	C_T/C_{max}[1]	S/S_v[1]
			a	1	0	1.2	0	0.79	0	0.79	0.79	0.22	0.482	0.010
		1	b	1	0	1.2	0	0.95	0	0.95	0.95	0.75	0.579	0.035
1.2	1.2		c	0.775	0.225	0.93	0.27	0.96(1.03)	0.28(0)	1.24(1.03)	1.24(1.03)	1.24(2.49)	0.756(0.628)	0.065(0.115)
			a	0.425	0.075	0.51	0.09	0.80	0.14	0.94	1.87	1.87	0.573	0.090
		0.5	b	0.217	0.283	0.26	0.34	0.58(0.82)	0.75(0.23)	1.33(1.05)	2.67(1.92)	2.67(3.12)	0.811(0.640)	0.144(0.148)
			c	0	0.5	0	0.6	0(0.73)	1.63(0.39)	1.63(1.12)	2.68(1.71)	3.26(5.20)	1.0(0.683)	0.199(0.251)
			a	0.708	0.292	0.425	0.35	0.76	0.31	1.07	1.07	1.07	0.652	0.058
		1	b	0.383	0.617	0.23	0.74	0.54(0.76)	0.85(0.48)	1.39(1.24)	1.39(1.08)	1.39(1.65)	0.848(0.756)	0.089(0.090)
0.6	1.2		c	0	1	0	1.2	0(0.65)	1.64(0.73)	1.64(1.38)	1.34(0.92)	1.64(2.50)	1.0(0.841)	0.127(0.136)
			a	0	0.5	0	0.6	0	1.63	1.63	2.42	3.26	1.0	0.199
		0.5	b	0	0.5	0	0.6	0	1.63	1.63	1.94	3.26	1.0	0.199
			c	0	0.5	0	0.6	0	1.63	1.63	1.34	3.26	1.0	0.199

[1] Figures in bracket refer to a situation where *fishing pattern* does not change when selection is changed from a) to b) or c) i.e. E_A and E_B for selection b) and c) are equal to E_A and E_B for selection a).

and

$$F_B = 0.6 - 2\ F_A$$

for $E_T = 1$ and $E_T = 0.5$ respectively. The lower catchability coefficient in area A will have the effect of diverting more effort to area B. The mesh selection alternative b) will here be quite satisfactory even if total effort is set equal to 1 (it would of course be desirable to have a lower fishing mortality than 0.74 in area B, see Fig. 1). The table illustrates how a quite satisfactory situation may be turned to a highly unsatisfactory one if there is an increase in efficiency in the young fish fisheries. This could for instance be brought about by the introduction of pelagic trawls on off-bottom concentrations of young fish. A doubling in efficiency would mean to move from a situation in the lower part of the table to the parallel one in the upper part.

The *per recruit* study from ULLTANG (1975), outlined above, illustrates how mesh size regulations and limitations on total effort (for example by a total quota) may change the fishing pattern. The main weakness with such studies is that changes in fishing pattern, created by variations in year class strength, are not taken into account.

A SIMULATION MODEL

For illustrating short and long term effects of a mesh change incorporating variations in year class strength, a modified model was constructed as follows:

Assume as above that the young (< 8 years) and old (≥ 8 years) fish are separated in the two areas A and B respectively, but in order to illustrate how a seasonal aspect can be taken account of, this separation is made effective only in the first half of the year. During the second half of the year all fish 3 years old and older are mixed and caught together in an area C. The assumptions about growth, natural mortality and age of maturity are unchanged. For each half year, a limitation is set on the total effort.

In a given year, let E_1 and E_2 be the total effort in the first and second half of the year respectively. E_1 is divided into $E_1 = E_A + E_B$, the division being dependent on cpue in A and B.

Let

C = catch in weight
N_i = number of age group i at the beginning of the year
w_i = weight at age i
r_i = proportion retained in the net of age group i with the mesh size in use.

Then

$$C_A = q_A E_A \sum_{i=3}^{7} \frac{N_i r_i w_i}{r_i q_A E_A + M} \left(1 - e^{-(r_i q_A E_A + M)}\right)$$

$$C_B = q_B E_B \sum_{i=8}^{15} \frac{N_i r_i w_i}{r_i q_B E_B + M} (1 - e^{-(r_i q_B E_B + M)})$$

(N_{15} = number of 15 years old and older fish. M = natural mortality during half a year = 0.1)

$$E_B = E_1 - E_A$$

Cpue in area A (C_A/E_A) and area B (C_B/E_B) will thus depend both on the number in the various age groups at the beginning of the year (which depends on recruitment and exploitation in past years) and E_A and E_B during the year, $cpue_A$ decreasing with increasing E_A and $cpue_B$ increasing with increasing E_A (decreasing E_B).

A computer program which searched for a combination of E_A and E_B which gave the same cpue in the two areas was applied. If no such combination existed all effort was allocated to the area with the highest cpue. In practice this was done by first calculating cpue in the two areas if all effort was allocated to area A ($cpue_{B,\ E_B=0} = \lim cpue_{B,E_B \to 0}$). If $cpue_{A,E_A=E_1} \geqq cpue_{B,E_B=0}$, then $E_A=E_1$, $E_B=0$. If $cpue_{A,E_A=E_1} < cpue_{B,E_B=0}$, E_A was gradually decreased until $cpue_A=cpue_B$. If equality was never reached, then $E_A=0$, $E_B=E_1$. The program then calculated catches in areas A and B, survivors of each age group at the beginning of the second half of the year, catches during the second half of the year ($F_{i,C}=q_C r_i E_2$) and survivors at 1 January next year. This was then done year for year forwards, putting in a recruitment = N_3 at 1 January each year. The program was run for a 20 years period. A fixed time-series of recruitment was drawn form a long-normal distribution with standard deviation = 0.8 (similar as observed for Arcto-Norwegian cod for years classes 1960–1974.) As starting population was taken in all runs the equilibrium population corresponding to $E_A=0.5$, $E_B=0$, $E_C(E_2)=0.5$; $q_A=0.5$, $q_B=1$, $q_C=0.5$; selection parameters $r_3=0.3$, $r_4=0.6$, $r_5=0.9$, $r_{\geqq 6}=1$ (selection a), and a constant recruitment corresponding to the mean of the log-normal distribution from which the recruitment series was drawn (i.e. equal to the geometric mean of the untransformed recruitment distribution and somewhat lower than the arithmetic mean which strictly speaking would have been the more appropriate).

In Fig. 3 are plotted the recruitment series (N_3) and the effort allocated by the model to area A together with biomass (B), and cpue (C/E) for each area, assuming a continuation with the same mesh size (selection a), unchanged q's and $E_1=E_A+E_B=0.5$, $E_B=0.5$, over the period. Catches (C_A, C_B, C_C and total catches C_T) are plotted in Fig. 4.

In Fig. 3–4 are also shown the corresponding results if in year 1 the mesh size was increased (and stayed there) to a size which gave selection c) ($r_{i\leqq 4}=0$, $r_5=0.3$, $r_6=0.6$, $r_7=0.9$, $r_{i\geqq 8}=1$).

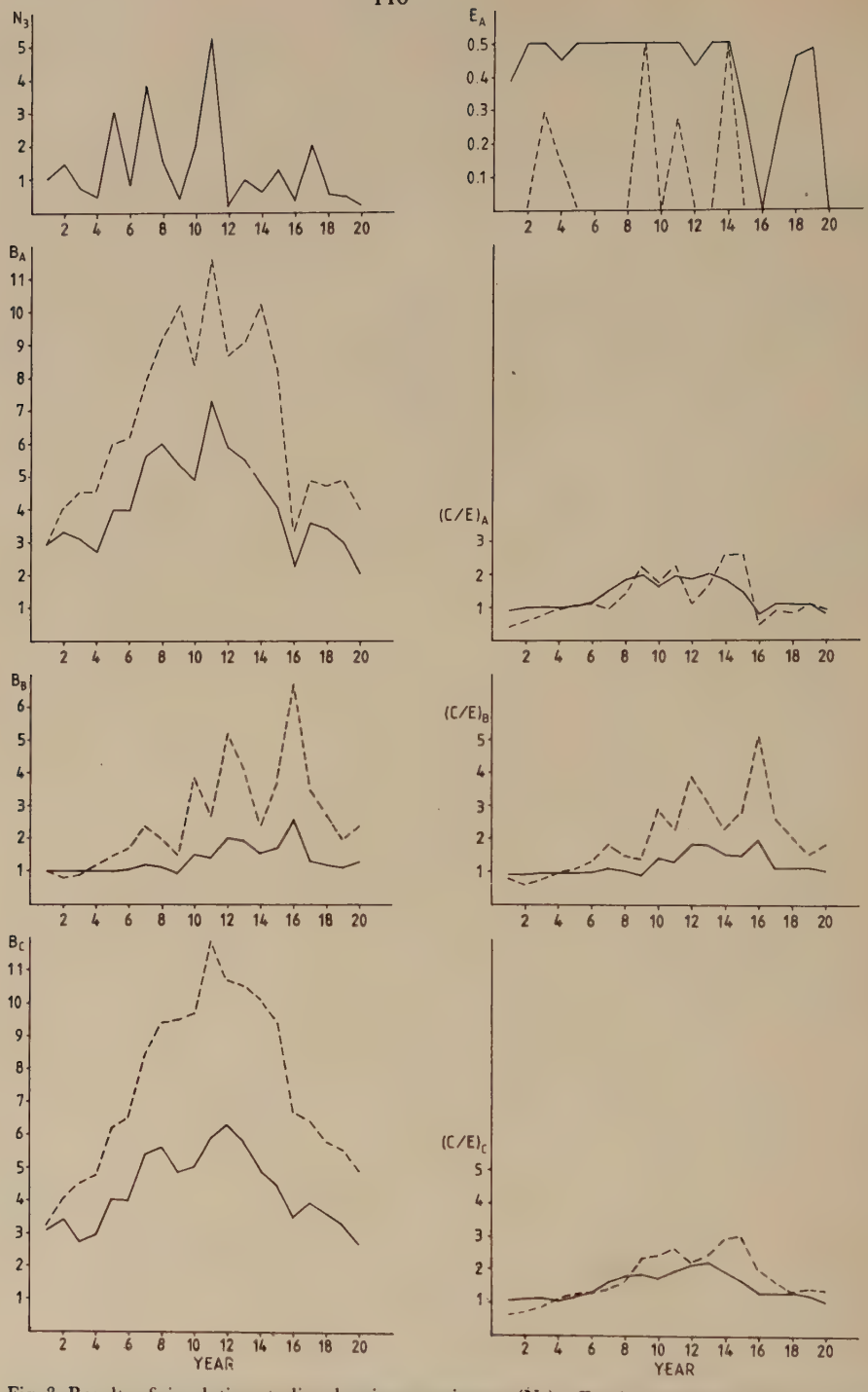

Fig. 3. Results of simulation studies showing recruitment (N_3), effort in area A (E_A), and resulting biomass (B_A, B_B and B_C) and cpue ($(C/E)_A$, $(C/E)_B$ and $(C/E)_C$) in the three areas. Solid line: Mesh selection a). Broken line: Mesh selection c).

Under selection a), most or all of the effort during the first half of the year goes to area A, with the exception of years 15–17 and year 20. In years 15–17 the strong year classes which recruited to the fishery in year 10–11 go into the adult stock at the same time as the young fish stock consists mainly of weak year classes. In year 20, three consequitive weak year classes have recruited to the young fish stock. In both these cases the result is an increase in $(C/E)_B/(C/E)_A$ sufficient to direct a significant part or all of the effort to area B.

Under selection c), effort fluctuates more between A and B, but the overall result is that much more effort goes to B. Taking the mean for the 20 year period, $E_A=0.412$ ($E_B=0.088$) under selection a) and $E_A=0.085$ ($E_B=0.415$) under selection c).

Since B_A is calculated over age groups 3–7 while the fish under selection c) first recruit to the fishery as 5 years old, B_A is not indicative of $(C/E)_A$ under selection c) to the same extent as it is under selection a). Thus, B_A has its maximum value in year 11 when an outstanding strong year class has recruited to the stock, and this year also $(C/E)_A$ under selection a) is very near its maximum value (despite that r_3 is only 0.3). Under selection c), $(C/E)_A$ reaches maximum in year 14–15 when this year class is 6–7 years old. It should also be noted that this year class in the latter case creates a very pronounced peak both in B_B and $(C/E)_B$ in year 16 when it is 8 years old, while under selection a) this peak is much less pronounced due to the much heavier exploitation through ages 3–5.

Selection c) results in significant lower total catches the first three years ("short term losses"). For the next 5 years the two mesh sizes results in more or less the same catches. Thereafter, selection c) gives much higher catches, the largest difference occurring in year 16 mainly due to the recruitment of the outstanding strong year class to area B. Generally, the difference in total catches is, to a large extent, arising from the high catches taken during the first half of the year (C_A+C_B) under selection c), although there also is a significant difference in catches taken in area C in most years after the first 8 years transitional period.

What would then the difference be between actual long term gains and short terms losses as simulated above and the corresponding results from traditional mesh assessment methods? In a traditional assessment, we would start with an estimate of mean exploitation pattern over a certain past period with the present mesh size (selection a)). This could be obtained from a VPA, averaging F on each age group over the period. If no significant changes in fishing pattern occurred during that period, we would probably get at an estimated fishing pattern similar to the mean fishing pattern over years 1–20 in the run with selection a) described above. This is as follows (absolute F-values):

Age	3	4	5	6	7	8+
F	0.137	0.274	0.410	0.456	0.456	0.338

(1)

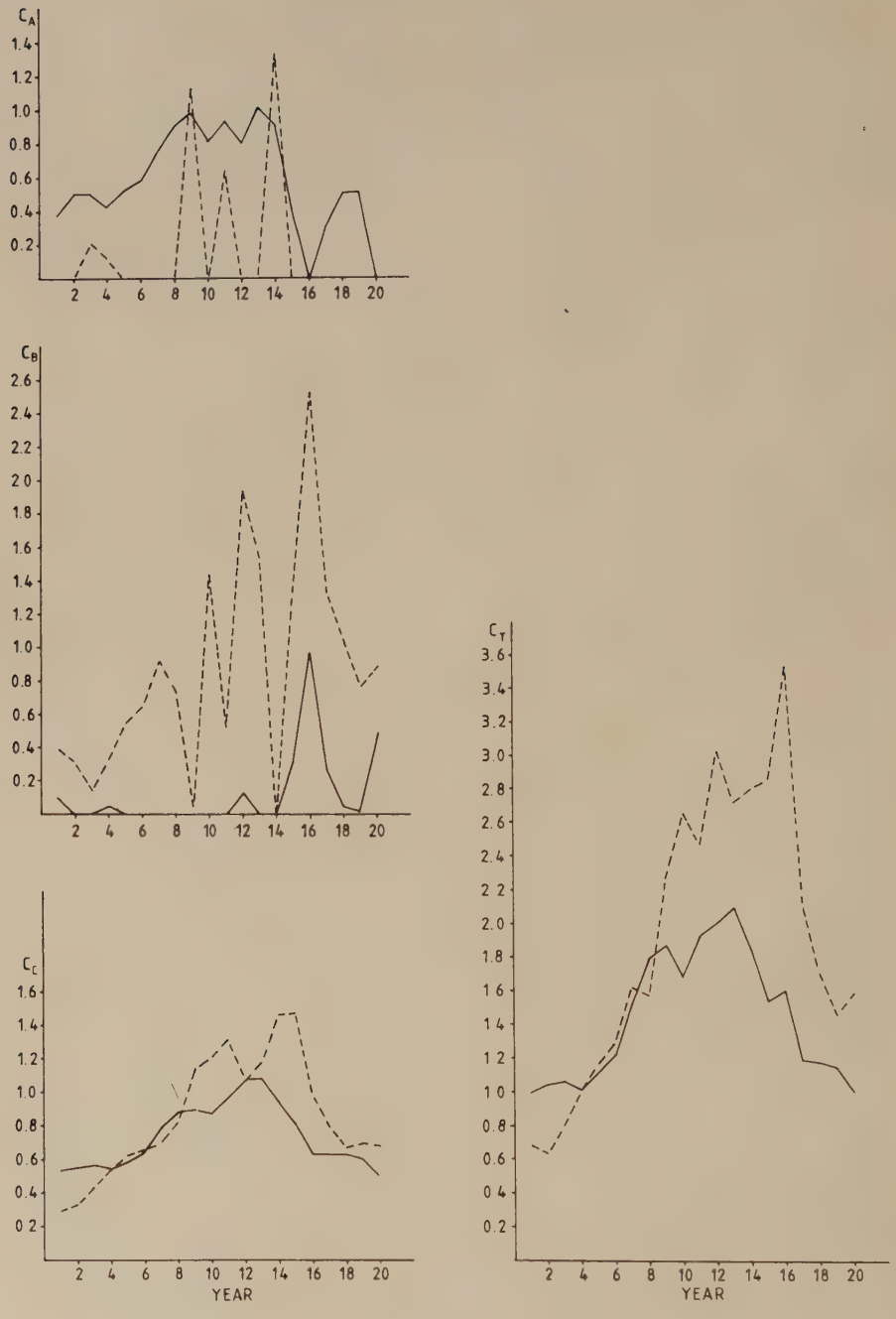

Fig. 4. Results of simulation studies showing catches by area (C_A, C_B and C_B) and total catches (C_T) for mesh selection a) (solid line) and c) (broken line).

Then, taking no account of changes in distribution of fishing effort if increasing the mesh size to the size corresponding to selection c), the estimated fishing pattern with selection c) is given by

$$F_{i,c} = \frac{r_{i,c}}{r_{i,a}} F_{i,a}$$

resulting in the following fishing mortalities with age:

Age	3	4	5	6	7	8+
F	0	0	0.137	0.274	0.410	0.338

(2)

These two fishing patterns would result in an estimated increase in Y/R from 1.054 to 1.370 by going from a) to c). Thus, the estimated *long term gain* would be 30.0%

The real gain over year 11–20 in the simulations carried out (Assuming that the benefits of the new mesh size are nearly fully attained after the first 10 year period) is 56.2%, i.e. nearly twice what would be estimated by traditional methods. However, the gain calculated in this way, even if it is taken over a period as long as 10 years, may fluctuate considerably due to varying recruitment. Specifically, comparing yields over years 11–20 for selection a) and c) will overestimate the long term gain for the following reason: The mean strength of the year classes recruiting to the stock just prior to year 11 is above the long term mean, and these year classes are exploited by selection a) in years 9–10 to a much larger extent than by selection c). Therefore, the yield of these year classes is to a significant extent falling outside the period used for comparison in the case of selection a), while this is not compensated for at the end of the period since the year classes then recruiting to the stock are weak. Taking into account a 2 years difference between first recruitment to the fishery under a) and c), it would be better to compare the yield under c) over years 11–20 with the yield under a) over years 9–18[1]. This gives 43.2% higher yield for selection c). This is much nearer the estimate obtained by calculating Y/R resulting from the mean F's by age over years 11–20 for selection c) as estimated in the simulation run and compare that with Y/R under selection a). The mean F's are

Age	3	4	5	6	7	8+
F	0	0	0.087	0.173	0.260	0.670

(3)

This gives a Y/R of 1.472 or 39.7% above Y/R for selection a).

It was also checked whether the larger difference in yield between a) and c) over the years 11–20 than indicated by Y/R calculations based on mean

[1] Of course, long term gains would be most effectively estimated by either extending the simulation period or repeating the simulation with different recruitment series.

exploitation patterns could arise from the yield of the dominating year class which recruited to the stock in year 11. However, the yield of this year class over the period was 39.3% higher for selection c) than a), i.e. almost identical to the 39.7% from Y/R studies. This is also what should be expected. Since under selections a) and c) most of the effort E_1 goes to area A and B respectively in a mean situation, the difference between the two exploitation patterns can not be expected to get significantly larger in a "unnormal" situation under the assumptions made in the simulations. One should rather expect the difference to get smaller since even under selection c) most effort might go to area A when a strong year class, still being immature, could be caught with that mesh size. In the specific example discussed above, this also occurred when the year class was 6 years old.

To conclude the discussion of long term gains, the simulation studies indicate an increase in yield of about 40% by going from a) to c) instead of 30% using traditional mesh assessment methods. If the fleet also in the second half of the year had the possibility of concentrating partly on young or old fish, the difference between the two estimates would have become larger. In Fig. 5 is compared year for year the yield derived from the simulation model (selection c)) with the yield assuming the constant exploitation pattern (2).

The *short term effect* of a mesh change will depend on the age composition in the stock when the mesh change is introduced and on the incoming recruitment. This is illustrated in Table 2 where the short term effects on total yield by going from a) to c) in either year 1, 4, 7, 10 or 13 are given. For comparison is also given the calculated short term effects from yield per recruit studies applying traditional mesh assessment methods (i.e. a change in mesh size creates exploitation pattern (2)). The most striking feature of Table 2 is the

Table 2. Short terms effects on bield (% increase in yield compared to continuing with old mesh size).

Years after change	Simulation model Year of mesh change					Y/R studies (no re-distribution of fishing effort)
	1	4	7	10	13	
1	−31.7	−31.2	−49.0	−35.5	−37.6	−41.8
2	−38.7	−38.0	−50.9	−38.2	−16.0	−32.8
3	−24.5	−35.3	−18.7	−27.4	8.2	−16.1
4	− 0.6	−28.2	8.6	−16.5	29.6	− 6.3
5	5.8	−21.1	13.3	37.5	14.7	4.8
6	6.2	10.6	30.3	65.6	11.1	12.6
7	5.8	46.0	17.4	110.0	12.0	18.3
8	−11.6	25.0	48.1	64.5	49.5	22.4
9	20.8	47.2	78.6	37.0		25.1
10	57.9	26.8	117.0	24.5		26.9

large differences between the different alternatives studied with the simulation model. The number of years the new mesh size has to be in effect before a positive gain is achieved varies between 2 and 5. If the new mesh size is introduced in year 13, i.e. at a time when a strong year class is recruiting to the fishery with the increased mesh size, and this year class being followed by relatively weak year classes, there is only a "short term loss" in the first two years. However, the gains during years 5–8 after the mesh change is much smaller in this case than for example in the case where the new mesh size was introduced in year 10, i.e. immediately before the year class could be exploited

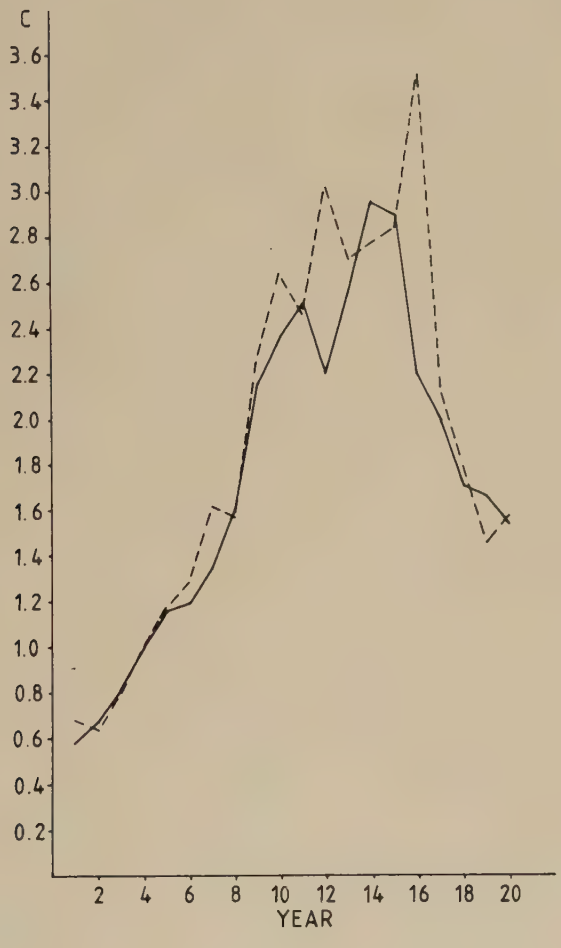

Fig. 5. Yield for mesh selection c) as estimated by the simulation model (broken line) compared with yield assuming a constant exploitation pattern as estimated by traditional mesh assessment methods (solid line).

by the smaller mesh size. The cost of waiting until the strong year class could be fished with the increased mesh size would be reduced medium-term gains.

Table 2 clearly illustrates how "short terms losses" traditionally estimated as differences in cpue in an average situation may be completely misleading when there are strong variations in recruitment.

It should of course be noted that mesh size regulations alone are generally not sufficient to optimize the yield from a fish stock, and that in most cases regulations of total allowable catch (TAC) has been regarded as the only practical way of limiting the overall fishing mortality. In the stock simulation above, TAC regulations combined with mesh size regulations could have further increased the yield, especially if the TAC's were broken down by area and seasons.

DISCUSSION

Although the model outlined above was constructed for the specific purpose of estimating effects of mesh size changes, its applicability is more general. The model may generally be used for estimating the distribution of fishing effort on areas with different age compositions, knowing the relative strength of the different year classes and the catchability coefficients. This makes it possible to refine estimates of the effects of regulatory measures as minimum mesh size or minimum landing size regulations. Varying price for different fish size categories could easily be taken into account by correcting cpue for fish price.

The model can only be used in cases where young and old (small and large) fish show rather clear differences in geographical distribution. The basic assumption in the model is then that the fishing fleet reacts to changes in cpue by at any time going to the area giving highest return. Because of haul to haul or local variability in cpue, there will be a lower limit for detectable differences in mean cpue, and even if the differences exceed this lower limit some fishing will be carried out in both areas (not necessarily by the same vessels) before they are detected. Some vessels may also for some reasons prefer to stay at a certain fishing ground even if it is known that higher catches may be obtained in other areas. Objective factors as distance from home port or landing site which directly influence the costs of fishing could be taken account of in the model, but more subjective factors as for example a preference for traditional fishing grounds would be more difficult to handle.

Therefore, the model can not be expected to predict with any high degree of precision the distribution of fishing effort within a specific fishing season, even if year class strengths, fish distribution and catchability coefficients were fairly accurately known. This does not necessarily mean that the estimated effects of for example a mesh size change on yield and stock size, calculated by

simulations over a number of years as done above, are in large errors. The model could, however, be developed further to take account of the various factors modifying the respond of the fishing fleet to differences in cpue.

In the simulation study described above, there was no overlap in age distribution between areas A and B. The model could easily be modified to cover for example the case were a year class gradually leave the young fish area and recruits to the adult fishery. In such a case differences in growth within a year class should be taken into account if the more fast growing individuals is leaving the young fish area first. This could be done by introducing different mean weights (w_i) and selection parameters (r_i) for the two areas.

The existence of fisheries with other gears (hand line, long line, gill net etc.) would have to be incorporated in the model, but would not mean a severe complication of the model itself. However, for applying the model in such a case the assumptions made about catch levels in these fisheries (e.g. unchanged effort or limitations by catch quotas) could be critical since different assumptions could have a very different effect on the cpue in the trawl fisheries in the two areas.

For using the model, estimates of the catchability coefficient q in each area are required. Assuming that estimates of fishing effort and resulting fishing mortality are available for a series of years, q may be estimated from the relationship $F = qE$. Fishing effort E may be estimated by $E = C/cpue$, while F may be obtained from VPA. ($F_{i,A} = F_i(C_{i,A}/C_i)$ where $F_{i,A}$ is fishing mortality on age group i in an area A, F_i total VPA-estimated F on age group i, and $C_{i,A}$ and C_i catch in number of age group i in area A and the total area respectively).

Because of the large variability often encountered in cpue data, the variance in estimated catchability coefficients would also often be large and could limit the usefulness of the model. Another problem could be time-trends in q, both limiting the number of past years which can be used for estimating q and questioning the validity of the estimates for predictive purposes. However, if an increase in catching efficiency over time occurs to approximately the same extent in each area, this would not create serious problems. It is q_A/q_B rather than the absolute values of q_A and q_B which is of importance. Higher catchability coefficients would simply mean lower effort values if fishing mortality is controlled by catch quotas.

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